

UNITED STATES PATENT APPLICATION
FOR
PRECISION LIQUID MIXING APPARATUS AND METHOD
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DESCRIPTION OF THE INVENTION

Field of the Invention

The present invention relates to an apparatus and method for precisely
consistently producing liquid mixtures according to a predetermined recipe, and a
5 particular embodiment for producing slurry mixtures at the point of use for chemical
mechanical polishing or planarization (CMP) processing of semiconductor wafers.

Background of the Invention

Much of current production CMP processing relies on mixing rather large
volumes of expensive slurry in a batch preparation process somewhat remote from the
10 point of use at a CMP workstation. The CMP processing requires many polisher
workstations and hence many wafers being processed with a consistent slurry for
uniform wafer results. Some slurries, particularly those including oxidizers, degrade
over time. Slurry degradation results from chemical reactions that start immediately
upon blending of the chemical components of the slurry. In order to maintain consistent
15 slurries, expensive metrological instrumentation and spiking systems monitor and
automatically correct mix concentrations. Often these bulk or batch slurry mixtures drift
so far out of specification that restoration becomes impossible, resulting in expensive
slurry waste.

More recent development has been directed to developing point of use slurry
20 blending, or on demand blending. In U.S. Patent No. 6,019,250, owned by the
assignee of the present invention, an apparatus and method is shown for dispensing a
liquid at one or more points of use from a plurality of reservoirs with a constant flow rate
of liquid. This apparatus and method include a programmable logic controller for

controlling valves for filling and dispensing the various liquid components to and from the reservoirs, and for controlling provision of a constant gas pressure in the reservoirs to effect the constant flow rate for the liquids. The disclosure of this patent is incorporated by reference into this application.

5 In another U.S. Patent No. 5,887,974, also owned by the assignee of the present invention, a slurry mixing apparatus is disclosed using a static mixer and/or a hopper mixer in which several streams of slurry concentrate and additive chemical components are pumped together as a single stream which is blended or mixed to produce a homogeneous slurry. The disclosure of this patent is incorporated by reference into this 10 application as well.

10 Other point of use slurry mixing and delivery systems are disclosed in U.S. Patent Nos. 5,478,435 and 5,407,526. In the system of U.S. Patent No. 5,407,526, slurry pumps preferably use a single motor to ensure the individual slurry component pumps are operated in phase for better control of the mixing of the slurry. In U.S. 15 Patent No. 5,478,435, the mixing of the slurry and diluting agent occurs at the point of use on the pad used in the CMP process. Liquid monitoring and control systems are used to maintain a consistent temperature and flow rate for the slurry components.

15 Even with such prior art on-demand or point of use slurry blending there is a desire for improved slurry consistency and greater flexibility in changing the slurry 20 recipe during CMP wafer processing. The term slurry has a well known meaning of a mixture of liquid and finely divided particles.

There exists a general need in industry to be able to produce consistent liquid mixtures from a plurality of selected liquid components according to a predetermined recipe. It is desired that the recipe be able to be varied for flexibility of operations as

well as to adjust the amounts of each liquid component not only as the desired recipe is changed, but as the characteristics of the liquid components change over time.

SUMMARY OF THE INVENTION

In accordance with the invention, a method, apparatus and system are provided for producing consistent liquid mixture according to a predetermined recipe. The apparatus comprises a plurality of liquid component reservoirs including an inlet port for loading a selected liquid component into a respective reservoir, and an outlet port through which the liquid component can be discharged. A gas manifold is provided for providing the same gas pressure within each reservoir. A plurality of valves are individually coupled to the respective outlet ports of the reservoirs. An electronic controller controls repetitive sequences actuation of the valves to discharge precise amounts or volumes of the liquid components from the reservoirs to provide the desired liquid components as doses which are mixed together to form the liquid mixture according to the predetermined recipe.

The apparatus and method of the present invention effectuate the production of the precise, consistent liquid mixtures from the embedded electronic controller either by varying the number of actuation cycles for the valves which all have the same actuation period, or by repetitively sequenced actuation of the valves while varying the actuation period of the valves, i.e., for normally closed valves varying the valve open periods.

In a preferred embodiment of the invention, a method, apparatus, and system are providing for producing consistent slurry mixtures to a point of use, such as a CMP polisher for semiconductor wafers. The apparatus comprises a plurality of slurry component reservoirs which include an inlet port for loading a selected slurry

component into the respective reservoir, and an outlet port. Gas supply means are included to provide the same gas pressure within each reservoir. A plurality of valves, preferably having relatively high activation rates, are individually coupled to the respective outlet ports of the reservoirs. An electronic controller controls repetitive sequenced actuation of the plurality of valves to discharge upon each valve actuation 5 precise doses of the selected components from the reservoirs to provide the desired components which are then mixed to form the predetermined consistent slurry.

The present invention also includes a system in which the apparatus of the present invention is in communication with a central operational controller which 10 determines the selected slurry recipe which is to be blended in the apparatus for use at the point of use. The system also includes a slurry component supplier including sources of slurry components and valves via which the components fill the plurality of component reservoirs.

In a preferred embodiment, the present invention takes on-demand liquid mixing 15 to a higher level with greater precision of resultant liquid mixture consistency and with flexibility in dynamically mixing recipes for specific CMP processing requirements. This system preferably permits varying the liquid mixture during wafer polishing and provides for rapid turn around for processing additional wafers to differing requirements.

The present invention preferably takes a different approach; mixing liquids such 20 as slurries immediately prior to use, in the precise quantities required (for example, in the CMP embodiment, 100 to 200 ml per wafer) and allowing dynamic control of the mix recipe during wafer polishing. By utilizing relatively high frequency, rapid opening and closing valves producing many small sequential "shots" or doses from each of several component reservoirs, one can achieve a precise, repeatable slurry mixing with a

statistical averaging algorithm applying to numerous very small shots as well as it applies to very large batches in achieving the desired slurry mixture.

At least three different valving techniques provide the desired valve actuation cycles to achieve the statistical averaging algorithm particularly in small mixture volume applications: 1. Solenoid driven valves, 2. Stepper motor driven rotary valves and 3. Pezio electric effect driven valves may be used to provide the repetitive small dose addition of slurry components from the reservoirs to achieve the desired slurry mixture.

5 Pressurized component reservoirs preferably hold enough of each component to process one wafer. A recharge module quickly refills these reservoirs just prior to wafer 10 polishing. Flow rate is controlled by maintaining the same reservoir dispense pressures coupled with hydraulic losses through the valves and static mixing elements. Each 15 component valve "opens" and "closes" sequentially the desired number of times in each recipe segment. While, preferably, only one valve is "open" at any time, more than one valve can be actuated at the same time to increase the component doses supplied in a given time period. Overlapping operation of adjacent valves can ensure consistent flow 20 rate of mixed product. The "open" time of each component valve varies depending on the current recipe segment requirements. Each recipe may consist of numerous segments, each segment may have a unique mix formula. Computer control enables dynamic recipe adjustment based on metrology of components (incoming chemicals), process results or product requirements. A flow sensor or scale monitors flow of the mixed product and reports flow rates at the end of each recipe segment to the host controller. The system takes configurable actions upon detection of insufficient or excessive flow rates, as defined with each recipe download. Recipes with variable flow rates are also possible.

In a preferred embodiment the design preferably supports five metered components and unmetered components although the number of components and reservoirs is a matter of choice. The mixing apparatus is integrated for operations with the CMP Polisher. The recharge components should be pressurized externally.

5 Process nitrogen, deionized water and cleaning chemicals provide flush/purge and cleaning facility.

Additional objects and advantages of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention will 10 be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

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BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate an apparatus, method and system consistent with the invention, and together with the description, serve to explain the advantages and 20 principles of the invention.

Figure 1 is a schematic illustration of the apparatus and system of the present

invention.

Figure 2A is a side elevation view of the apparatus of the present invention partly broken away and partly in section to illustrate the reservoir structure and discharge valving.

Figure 2B is a side elevation view of the apparatus of the present invention partly broken away at an angle to the longitudinal axis to illustrate the reservoir structure.

5 Figure 3 is a timing chart for the valve opening times for the five component

reservoir embodiment and illustrating the repetitive sequencing of the five high speed valves.

10 Figure 4 is an electrical schematic of the electronic control scheme used in the present invention.

Figure 5 is a flow chart illustrating the steps in the method of the present

invention.

Figure 6 is a top plan view of a mixing substrate which is included in the mixing

and flow measuring section.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

15 Reference will now be made in detail to an implementation consistent with the present invention as illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings and the following description to refer to the same or like parts.

20 While the invention has application to the precise, consistent mixing of liquid components to produce a liquid mixture according to a predetermined recipe, a preferred embodiment of the invention will be described for slurry mixtures at a point of use.

Figure 1 illustrates schematically the system and apparatus of an embodiment of the present invention with the slurry blending system 10 including the point of use slurry blending apparatus 12 which is coupled communication-wise to a central remote host control operations center 14 via a communication link as shown, which can be hardwired, or linked by an rf or optical link, not shown. The central control operations center 14 controls a number of point of use slurry blending apparatus 12 and the CMP polishing workstation 13 with which the apparatus is used.

5 The system 10 includes a slurry component supplier 16 and gas pressure supplier 18 both of which are connected to the apparatus 12 as will be described in detail below. The slurry component supplier 16 includes a plurality of slurry component supply members, 17-1 through 17-5 which provides metered components and supply member 17-6 provides unmetered components, with supply control valves, not shown, which control the supply of the necessary slurry recipe components to the point of use apparatus 12.

10 15 The apparatus 12 is seen schematically in Fig. 1 and in side elevation with a partial sectional view in Figs. 2A and 2B. The apparatus 12 includes the following sections starting from the top; a gas manifold section 20 which is connected to the gas pressure supplier means 18 to allow a constant pressure of inert gas, such as nitrogen to be maintained in the five generally cylindrical reservoirs 22-1, 22-2, 22-3, 22-4, and 20 22-5 which comprise the reservoir section 24. These five reservoirs 22-1 through 22-5 are arranged in an annular array spaced about a central longitudinal axis of the generally cylindrical apparatus 12. While five reservoirs are shown in the embodiment of the invention described here, the number of reservoirs can be varied. The five reservoirs allow for the inclusion of enough slurry components to meet most slurry

recipe demands. The number of valves preferably should match the number of reservoirs provided. The reservoir volume is chosen to hold enough of the different component to satisfy the slurry requirements for polishing a single wafer. The 5 reservoirs, by way of example, each have a volume of 100 milliliters. The bottom extending end of each reservoir has a generally cone shaped end closure 26 with a central outlet port 28 leading to outlet passage 30 connecting to the high speed valve section 32.

A valve section 32 is disposed below the reservoir section and includes five high speed solenoid valves, 34-1, 34-2, 34-3, 34-4, 34-5, with one valve coupled to a 10 respective reservoir. The valves are mounted transverse to the longitudinal axis of the generally cylindrical reservoir with which it is connected. The outlet passage 30 is connected to the valve inlet and the valve outlet is connected via valve outlet passage 36 to the mixing and flow measuring section 38. While a variety of well known 15 techniques can be used for mixing the precise component doses which are supplied for mixing the slurry components, in a preferred embodiment a smear mixing chamber 39 is included in the mixing and flow measuring section 38. The mixing and flow measuring section 38 includes a mixing chamber 39 spaced below the valve outlet measuring section 38 includes a mixing chamber 39 spaced below the valve outlet passages 36 with a central aperture 42 through a generally planar smear mixing 20 substrate 40. Flow measurement sensor means 43 is included in section 38 for measuring the blended slurry flow rate as the slurry is discharged from central aperture 42 onto the CMP workpiece. The smear mixing chamber 39 is defined by annular side walls, the bottom substrate and a top wall. The outlet passages 30 continue into apertures in the top wall. The mixing chamber has, by way of example, a very small height of about 0.020 inch between the bottom substrate and the top wall. In order to

promote mixing of the dosed components, a plurality of annular grooves are formed in the top wall of chamber 39 in a preferred embodiment. These annular grooves are concentrically disposed about the central aperture 42. These annular grooves are spaced concentrically with the width of the grooves being about 0.25 inch and the groove depth being about 0.060 inch.

The smear mixing substrate 40 is seen in Figure 6 in a top plan view. The smear mixing substrate 40 is a circular planar substrate which forms the bottom of mixing chamber 39 which has a volume of, for example 1-2 milliliters, in the mixing and flow measuring section 38. A central discharge aperture or orifice 42 is provided through the substrate 40. The five dotted line circular patterns 41 illustrated near the periphery of substrate 40 represent the initial component doses discharged from the five component reservoirs via the valve outlet passage onto the substrate. The liquid component doses rapidly spread out in enlarging circular patterns and are followed by repeated doses from the repetitive sequential openings of the individual valves. The spreading liquid component doses are smeared and mixed together into the desired slurry mixture which is discharged through the central aperture 42 onto the CMP workpiece. A flow sensor 43 is mounted at the exit side of substrate 40 proximate the central discharge aperture as illustrated in dotted line schematic fashion.

An electronic control section 46 is seen mounted on the side of apparatus 12 in the schematic view of Fig. 1, and can be mounted in any convenient location on the apparatus 12 with wiring connection from the microcontroller 48, seen in circuit schematic of Fig. 4, going to the central operation control center 14 for communication of data. The electronic control section 46 will be explained in detail below, including how it is connected to the high speed valves to control the opening of these valves.

A slurry component feed line 48 extends from the slurry component supply 16 to each reservoir to permit filling of the respective reservoir with the selected slurry components, which are typically a slurry concentrate, oxidizer such as hydrogen peroxide, deionized water, and other selected chemical components as are well known and used in CMP processing.

5 and used in CMP processing.

A second feed line 50 also extends into the mixing and flow measuring section 38 to permit an unmetered flow of deionized water or other fluids to flood the mixing chamber for purging and cleaning the system after a slurry blend has been discharged, or for providing deionized water or other chemical agent to the wafer through the mixing

10 chamber central exit aperture.

A preferred difference of the apparatus of the present invention from other point of use slurry blending systems is the highly precise and consistent slurry blends that can be formulated and deposited onto the CMP workpiece. Preferably, the apparatus of the present invention allows for optimization of the slurry recipe for specific CMP requirements. In addition, it preferably permits varying the slurry recipe during wafer polishing. This is accomplished by the very accurate control of the slurry components which are added to form the liquid mixture according to the predetermined recipe as a result of repetitive sequential actuation of the high speed valves to discharge from at least two doses and preferably from about 5 to 20 small doses, of programmable 15 volumes of selected component, per valve opening. These doses are discharged at the periphery of substrate 40, and the doses rapidly spread in a circular pattern on the substrate 40 and mix with the doses of the other slurry components in a smear mixing 20 which takes place on substrate 40 as the mixture advances to the central discharge aperture 42.

The dose volume of a specific selected slurry component is controlled in a preferred embodiment by controlling the valve open time of normally closed valves. This is best seen in Figure 3, which illustrates the periodic, near square wave, valve open signal which is applied in repetitive sequence to the respective valves for the selected component. There are five plots 52-1 through 52-5 for the valve open signals applied to the respective five valves, and the duration of the valve open signals controls the volume of slurry component which flows under the constant pressure from the reservoir into the mixing and flow measurement section. This valve open signal is plotted against time in milliseconds in Figure 3. This figure illustrates that the component valves are opened in sequence from component 1 to component 5, and then this valve opening pattern is repeated until the recipe segment is completed. In the example of Figure 3, there are 6 valve open cycles for each of the component valves which provides a high level of precision and accuracy of the component proportions in the slurry blend based on compensating for the random valve errors. Even greater precision of the component proportions can be had by increasing the number of valve cycles, so that at 20 valve open cycles for every recipe segment the random valve errors are almost entirely eliminated. For small liquid mixture batches with high mixing ratios, the duration of the valve open periods per opening can vary from a few milliseconds to hundreds of milliseconds. As can be seen from the example of Fig. 3, the repeated sequence of six valve openings for each component is shown as completed in a little over 200 milliseconds, although with the embodiment shown the valve open times can be up to 255 milliseconds. For these small liquid mixture batches as described above, in order to ensure thorough mixing and precise accurate component mixtures the actuation of the valves where a selected number of actuation

sequences are employed should be such that the valves are actuated open for short durations of from about 1 to 255 milliseconds. The higher valve actuation rate permits use of wider mix ratios of components.

In an alternate embodiment, the predetermined recipe is implemented by a 5 control algorithm where the valves are controlled to have varying actuation open time periods with at least two actuation cycles.

When large batches of liquid components are to be precisely mixed, the valve actuation periods and cycles need not be at such high rates and short time periods as for the small batches described in the preferred embodiment described above.

10 The microcontroller 54 is the major element in the electronic control section 46, and the electrical circuit schematic shows microcontroller 54 connected to the various elements of the system 10 as seen in Figure 4. The preferred microcontroller is a product of Microchip Technology, Inc. of Chandler, AZ, and is product number PIC18C452. The microcontroller 54 performs the following basic functions. The 15 microcontroller performs the communication with the host operation controller 14 to receive and confirm recipe instruction. It is connected to a flow meter in the mixing and flow measuring section to provide feedback on the slurry blend flow rate and completion of delivery of the blended slurry to the workpiece. It performs error detection functions via connection to sensors on the reservoirs which measure the fluid levels in the 20 component reservoirs, and from a variety of sensors which indicate that the slurry component supply means is ready to supply slurry components to the reservoir.

The microcontroller 54 is connected to each of the five high speed valves 34-1 through 34-5 to control the application of the valve open signals to the solenoid which controls opening of the valve, and the microcontroller 54 controls the duration of the

valve open signal and the repetitive sequencing of the valves. The high speed valves are preferably solenoid valves. By way of example the high speed valves are solenoid valves sold under the tradename BIO-VALVE and supplied by the FURON division of Saint Gobain Performance Plastics.

5 The preferred microcontroller 54 is a 40 pin surface mount device with a serial communications port for communicating with the host operation controller. Preferably, microcontroller 54 has in-circuit programming capability with 32K of program memory and 1536 bytes of data memory.

10 The microcontroller 54 which is a very high speed device operating at about 40 MHZ is connected to the solenoid valves by individual octal driver latches which permit the very high speed microcontroller to supply operating signals to the solenoids which operate at speeds of up to about 300 hertz, which is a relatively high speed for valve operation.

15 The microcontroller 54 is seen schematically connected to other system elements in Figure 4. A source of potential 56 provides power to the microcontroller as well as to the valve solenoids 58 via octal driver latch means 60. While a single means 60 and solenoid 58 are shown in Figure 4, it should be understood there are five individual means and solenoids since there are five valves and component reservoirs. The microcontroller is shown connected to ground means 62 and a programming means 64 for in-circuit programming. As mentioned with respect to Figure 1, the host operation controller 14 is coupled via a serial data link to the microcontroller 54, with host operation controller 14 providing slurry recipe information and general control information to ensure integration of the operation of apparatus 12 with the other equipment, including CMP workstations 13. The microcontroller receives sensor data

from sensor means 66, which includes a variety of sensors for measuring slurry flow and for measuring the liquid levels in the reservoirs. Enable and ready means 68 provides input to and receives feedback from the microcontroller regarding the status of ancillary support and safety means.

5 The microcontroller 54 receives sensor inputs from the slurry flow sensor and from sensors associated with the reservoirs which indicate the relative volume of component in each reservoir. In this way the microcontroller monitors the slurry blending process. Sensors associated with the slurry component supplier means and the gas pressure supplier provide inputs to the microcontroller as safety signals to prevent initiation of the slurry blending cycle if there is an interruption of these important 10 supplies. The slurry recipe data is provided from the host operations controller and is stored in the microcontroller memory for use in carrying out the slurry blending operation.

Just prior to each wafer process, the electronic controller receives a recipe 15 download from the host operation controller. This recipe contains the sequence of valve actuation times that describe the proportions of the required (or desired) mixture. In addition to the valve actuation times the recipe also includes iteration factors that the electronic controller applies to each recipe segment during recipe execution. Each iteration or repetition of the recipe segment valve timing reduces the random error by a 20 statistical averaging process. The more iterations the greater random error reduction.

The operation and process for the blending of the slurry components is shown in a flow chart in Figure 5. When a slurry recipe blend is to start, the microcontroller determines in step 510 whether the reservoirs are full, from the high liquid level sensor. If a reservoir is not full, the microprocessor transmits a vessel refill request code in step

515. When all reservoir vessels are full, the microprocessor terminates the refill request at step 520.

When the reservoir vessels are all determined to be full, the microcontroller receives a signal from the host operation controller indicating whether to reuse the 5 current slurry blend recipe which was used last, see step 525. If the indication is that a new recipe is to be used, the microcontroller receives the total number of recipe segments in step 530, and can receive and store up to 100 recipe segments at step 535, which recipe segments are for use during the sequential CMP processing steps on a given wafer. The microcontroller receives at step 540 the recipe segment length, and 10 at step 545 calculates the recipe required valve open time pulse width modulation values, and transmits back to the host controller the confirming recipe data at step 550. If the determination at step 525 is to reuse the current recipe, the process advances to step 550 at which there is a transmission confirming the recipe data to the host controller 14 with receipt of recipe confirmation at step 555. A yes signal will send the 15 blend ready signal at step 560. If the recipe is not confirmed, a recipe error signal is generated at step 565, followed by a determination at step 570 of whether the limit is exceeded for the error signal. If the limit on retrying to confirm the recipe is not exceeded the process returns to step 530. If the limit is exceeded, a failure signal is communicated at step 575 to the send blender not ready signal step 580 which puts the 20 blender apparatus in a sleep mode at step 585.

If the recipe is confirmed at step 555, a start blending signal is received at step 590 followed by a generate blending valve sequences step 600, a check flow meter step 610, and a recheck after a minimum time of whether the flow rate is in range at step 620. If the flow rate at step 620 is not in the desired range, a send flow error step 620.

5 signal is sent out at step 640. If the flow rate is within range, the blending continues until the recipe is finished at step 630, after which a blending complete signal is sent at step 635, and a send blender not ready signal at step 640, followed by the apparatus being placed in sleep mode at step 585. If the recipe is not finished the process returns to the generate blending valve sequence step 600 and the process proceeds until the recipe is finished.

recipe is finished.

In the CMP processing workstation a robot positions the semiconductor wafer for polishing, and the reservoirs of the apparatus of the present invention are refilled during the positioning. The new recipe from the host controller is downloaded and confirmed.

10 On receipt of a start signal from the host controller, the point of use apparatus blends the recipe segments as specified in the recipe stored in the microcontroller memory. As each recipe segment is completed, confirmation flow rate data is sent to the host controller. When the recipe is completed, or upon receipt of the other instructions, the point of use apparatus returns to a standby station, and executes a partial system flush/purge and waits for the next wafer. If the apparatus is idle for an extended period

15 a complete system flush/purge ensures fresh slurry for the next wafer.

This invention has the ability to execute unique recipes for each wafer processed. The resolution of recipe adjustment is sufficiently fine to allow correction for variations in incoming chemicals, changes in target process performance, or other measurable factors. This capability provides several process advantages.

20 measurable factors. This capability provides an opportunity to improve the quality of the product. In current bulk chemical dispense systems, chemical concentrations vary from the ideal. These variances result from inaccuracy in the mixing/diluting methods employed during chemical preparation, time since preparation, storage conditions, etc. Measuring the concentration of a pure chemical is generally far simpler than attempting

to measure the concentration in a complex mixture (like a CMP Slurry). Many bulk delivery systems include instrumentation (conductivity, density, pH, specific ion, etc.) that report this parameter to a central factory control and monitoring system (FCMS). This information is often readily available in the typical semiconductor fab facility. The 5 electronic controller in the present invention can be programmed to adjust the ratios of valve actuation times between the up to five liquids such that variations in incoming chemical concentrations can be eliminated from the resultant mixed liquid.

The behavior of the mixed liquid at the point of use is likely to vary over time, as 10 other process conditions change. The invention can be programmed to adjust the ratios of valve actuation times between the up to five liquids such that process variations from wafer to wafer or batch to batch can be minimized.

The flow of parts through a process step may produce variations in the required 15 process behavior from part to part. These variations could be due to differences in the structure of the parts, variations in previous process steps, or variations in the intended use of the parts. The invention can be programmed to adjust the ratios of valve actuation times between the up to five liquids such that the effect of the process step on the part is customized to the specific requirements of that part. Such adjustment can be used to allow parts to flow through the process step in any desired order, eliminating 20 batching of parts and manual setup of machinery between batches. This adjustment can also be used to compensate for measurable variances in the parts, due to previous process steps.

Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. It

is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the following claims.